Clouds and the Earth's Radiant Energy System (CERES)

Validation Document

Validation of Imager Cloud Optical Properties (Subsystem 4.3)

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VALIDATION OF IMAGER CLOUD OPTICAL PROPERTIES

Abstract

Cloud physical and optical properties determine how clouds affect the radiance and flux fields at the surface, within the atmosphere, and at the top of the atmosphere. In the Cloud Property Retrieval Subsystem (COPRS), CERES analyzes individual pixel radiances to derive the cloud properties that influence the radiation fields. For each pixel, state-of-the art methods are used to ascertain the temperatures and pressures corresponding to the cloud top, base, and effective radiating center; the phase and effective size of the cloud particles; the cloud optical depth at a wavelength of 0.65 µm; the cloud emittance at 10.8 µm; and the cloud liquid or ice water path. An approach for validating these remotely sensed cloud properties is described in this document. The strategy includes both pre-launch and post-launch comparisons of the satellite imager-derived cloud properties with those determined using other methods or datasets. In some cases, the values from the other techniques are more accurate and, therefore, serve as "cloud truth." Simultaneous retrievals from two different satellites provides an estimate of the relative errors in the retrievals and their dependence on angular configuration, climate regime, and surface type. Theoretical calculations are also used to study the sensitivity of the algorithms to various errors in input data and in some of the basic assumptions. Assessments of overall absolute errors are obtained through comparisons of the COPRS products with coincident datasets from field programs and well-instrumented, long-term monitoring sites. The required correlative data for validation include surface and aircraft measurements of the subsystem parameters using lidars, radars, in situ microphysical probes, microwave radiometers, and sunphotometers. Additional sites are required to obtain correlative data representative of additional climate regimes. New field programs with in situ aircraft measurements are needed to enhance and verify the accuracy of the cloud properties derived from surface observations. Successful validation is effected by a stable estimate of the product uncertainties.

4.3.1INTRODUCTION

4.3.1.1 Measurement and Science Objectives

The CERES Cloud Property Retrieval Subsystem (COPRS; see Minnis et al., 1995) will employ state-of-the-art methods to derive cloud bulk and microphysical properties from the relevant spectral radiances available from the VIRS, MODIS, and AVHRR imager instruments operating during the EOS era. These parameters must be measured simultaneously with the broadband radiation field to further our understanding of how they affect the exchange of radiation within the atmosphere and how they can be used to improve the interpretation of the measured broadband radiances (Wielicki et al., 1995).

A wide variety of methods are used to derive the COPRS products. The subsystem uses state-of-the-art procedures to arrive at the most accurate values for each parameter. It combines several algorithms to cover as many cases as possible. This document describes the strategy being implemented to insure that the COPRS products are consistent with the standards necessary to meet CERES overall accuracy goals.

4.3.1.2. Missions

This subsystem will be operating concurrently with the CERES scanners that are scheduled for launch on TRMM, AM-1, and PM-1. The COPRS will also be exercised prior to launch using AVHRR and ERBE scanner data on the NOAA-9 and NOAA-10 Sun-synchronous satellites. The AVHRR measures radiances at 0.65, 0.86, 3.7, 11, and 12 µm with a nominal resolution of 1 km. During the TRMM mission, COPRS uses VIRS as the primary radiance data source for the determination of geophysical parameters. The VIRS measures five spectral radiances centered at 0.65, 1.61, 3.7, 11, and 12 µm. The VIRS resolution is 2 km. MODIS will be scanning on the AM-1 and PM-1 platforms. It has a total of 36 channels with resolutions ranging from 0.25 to 1 km. The COPRS primarily uses MODIS data taken at 0.67, 1.61, 2.12, 3.73, 8.55, 11, and 12 µm with all pixels averaged to a common resolution of 1 km.

4.3.1.3 Science Data Products

The COPRS is applied to each imager pixel that has been identified as cloudy by previous subsystems. COPRS determines the phase, effective particle size, optical depth, emittance, non-vapor water path, radiating temperature, pressure, and thickness (cloud base) of the cloud within a given CERES pixel. These imager-pixel cloud properties are used in a later subsystem to determine an average set of cloud properties for each CERES scanner pixel (~25 km x 25 km).

4.3.2VALIDATION CRITERIA

It is assumed that radiances used in COPRS have already been validated (section 4.0). Therefore, this validation plan only encompasses higher order products. Although cloud thickness, pressure, and radiating temperature are COPRS products, they are closely related to cloud-top and cloud-base heights. Therefore, the validation approaches discussed in section 4.2 also apply to those three COPRS parameters. The verification strategy discussed here will primarily be directed to cloud phase P, effective droplet radius r or effective ice crystal diameter D, optical depth τ, emittance ε, and water path WP. Determination of the uncertainties in each property will be made for both daylight and nocturnal conditions.

4.3.2.1 Overall Approach

The validations will operate with two empirical phases, pre-launch and post-launch, and an ongoing theoretical phase. The empirical phases refer to validation techniques that compare results derived from measurements. These efforts also include consistency studies that use multi-angle satellite or satellite/aircraft views. The theoretical phase refers to sensitivity and limitation studies performed using radiative transfer calculations and retrievals of cloud properties from simulated datasets.

This validation strategy attempts to ascertain to what degree the COPRS products meet the CERES accuracy goals. Table 4.3-1 summarizes the state-of-the-art and desired accuracy goals for COPRS. The values in this table are optimistic estimates based on published reports, theoretical studies, and examination of selected available datasets. These numbers are realistic for situations that currently can be resolved with existing techniques. They do not apply to conditions that resist analysis using state-of-the-art satellite remote sensing methods. For example, during the night and near-terminator conditions, clouds become thermally black for $\tau > 8$ in the infrared wavelengths used to retrieve cloud properties at those times. Thus, it is not possible to determine any of the properties except for ε and phase to the levels of accuracy in the table. Even the phase will be suspect for cloud temperatures T_c between 273 and 233K. Similarly, these numbers assume that only a single-layer cloud is observed. If multiple cloud layers coexist in a single pixel, the accuracy of the retrieval will be compromised significantly.

Given such extreme limitations, it useful to reiterate the scientific use of these products within CERES . The cloud properties will be related to radiative fluxes at the surface, within the atmosphere, and at the top of the atmosphere. Shortwave (SW) irradiance is more sensitive to τ, r, P, and WP than longwave (LW) flux. For example, if a cloud is thermally black, the effect on the LW is essentially the same for $\tau = 10$ as it is for $\tau = 100$, or for $r = 4$ μm as it is for $r = 20$ μm. However, the transmittance or reflectance of a cloud to SW radiation will be substantially different for those different cloud properties. Except for the effect of cloud-base height, the optical depth limitation at night will have minimal impact on the scientific use of the COPRS for radiative flux determination.

Remote sensing of most of the parameters (e.g., r, WP, P) listed in Table 4.3-1 is a relatively new activity. On the other hand, the determination of some of these parameters at the satellite pixel scale using other techniques is also limited. This limitation may yield a validation reference that is nearly as uncertain as the remote sensing value. These constraints are discussed further in the next section. Because of these limitations, the wide variety of cloud conditions, and environment, validation of these cloud properties is a difficult problem. By approaching the validation process from several avenues and seeking consistency between the various methods, it is expected that the resulting estimates of uncertainty in each parameter will be reliable and defensible.

TABLE 4.3-1. COPRS ACCURACY SUMMARY

Parameter	Current Accuracy		CERES Accuracy	
	Daytime	Night	Day	Night
Phase (%)	20%	40%	10%	20%
r / D (μm)	25%	50%	15%	25%
τ	25%	50%	25%	35%
ε	5%	15%	5%	5%
Liquid WP (gm^{-2})	35%	70%	25%	35%
Ice WP (gm^{-2})	50%	100%	25%	35%
Δz	50 hPa	100 hPa	25 hPa	50 hPa

4.3.2.2 Sampling requirements and trade-offs

Many factors affect the retrievals of cloud microphysical properties. Among the more important variables are the viewing and illumination angles, clear-sky radiances and their uncertainties, temperature profiles, cloud-cell size and spacing (or degree of plane "parallelness"), horizontal and vertical inhomogeneities, and the parameterizations used in the algorithms. Theoretical studies can be used to estimate the potential errors arising from each of these factors and from their combined impact. However, the empirical approaches are critical for determining the magnitude and sign of the errors in real clouds. Both types of analysis are essential to both quantifying and understanding the errors in the COPRS products.

a) DATA INTERCOMPARISONS

Comparisons with cloud truth data constitute the primary technique for establishing an "absolute" accuracy measure. There are many factors that must be considered in any comparison of satellite data with ground-based or aircraft measurements. The most important aspect is the absolute accuracy and precision of the "truth" values. Another primary factor is matching of the truth set with the satellite pixels. Serious scale differences can exist between the pixel and correlative data. For example, a ground-based radar measures only a linear sample of the clouds having a width of only a few tens of meters. The cloud sample is an advected quantity that may change with time. The satellite pixels are taken nearly instantaneously and integrate the effects of clouds over an area that is a few orders of magnitude greater than the radar area. Similarly, the aircraft only samples a small linear portion at one or a few levels within the cloud volume. Therefore, the comparisons with the satellite data must be carefully executed using various statistical approaches.

Some of the scale problems can be minimized using high-resolution remote sensors, such as the MAS, on aircraft and satellites (e.g., Landsat). These radiometers yield pixel sizes that are comparable to those of other instruments. Retrievals can be performed on the small pixels and compared directly to coincident in situ and active remote sensing (e.g., radar) determinations of the same parameter (e.g., Nakajima and King, 1992?). The small aircraft pixels, however, may not be representative of what the satellite views because of differences in scale and viewing conditions. To alleviate some of that discrepancy, radiances and/or retrievals from individual pixels can be integrated to approximate the satellite view. Retrievals from the corresponding satellite data or from the averaged aircraft radiances can then be compared to the mean aircraft-derived properties for a given view (e.g., Heck et al., 1993). The overall uncertainty then is a combination of the aircraft-reference difference and the satellite-aircraft difference. Included in the former error is the inherent uncertainty in the reference data (in situ, active sensor).

Another approach is to use in situ data to verify or tune a radar or lidar retrieval of the vertical structure of cloud particle size, phase, and water content (e.g. Intrieri et al., 1995; Matrosov et al., 1995). Vertical and horizontal integration of these quantities provides estimates of r, D, P, and IWP comparable to the satellite retrievals. Here again, small-scale in situ data are used to establish the accuracy of a somewhat lower resolution sensor that, in turn, becomes the "truth" source for the satellite data. The radar or lidar data can then be analyzed over significant time periods for a variety of background surfaces and climate regimes. The quantities from the active sensor can be averaged over time intervals that correspond to a certain number of satellite pixels. Radars or lidars at the surface or on aircraft can be used to establish cloud base heights or cloud thickness for similar comparisons with the satellite retrievals (e.g., Uttal et al., 1995). Cloud-base heights can also be accurately determined using ceilometer measurements for clouds below 4 km (e.g., Miller and Albrecht, 1995).

Uplooking microwave radiometers provide a validation source for liquid water path LWP (e.g., Minnis et al., 1992; Han et al., 1995). The approach for validation would be very similar to the radar-satellite comparison. Downlooking microwave instruments can also be used to determine cloud LWP over the ocean providing a large-area validation reference. There are several techniques available for interpreting these data (e.g., Petty and Katsaros, 1990; Curry et al., 1990; Lin and Rossow, 1995) that have various levels of uncertainty depending on the clouds. The various microwave measurements should be valuable for verifying both LWP and P in a variety of conditions.

Cloud optical depth can also be validated, to some extent, using sun photometers, lidars, and narrow-band flux radiometers at the surface. The former two instruments are most useful for determining optical depths for $\tau < 5$ (Shiobara et al.., 1996; Wylie et al., 1995), while the last one may be more applicable to larger optical depths. The approach for these instruments is similar to that used for the radars. Emittance and optical depth for thin clouds can be determined from radiance measurements from ground-based and airborne infrared radiometers or interferometers when used in conjunction with lidar and radiosonde data (e.g., Ackerman et al., 1995; Collard et al., 1995). Such values are reliable for single-layer clouds and can serve as sources for emittance validations. Similarly, lidar and radar data can be used with radiosonde data directly to determine effective cloud emittance for thin clouds.

Direct comparisons of in situ data with retrieved properties are important but, because of their difficulty, are extremely limited. For example, Platnick and Valero (1994) and Nakajima and Nakajima (1995) were only able to compare their AVHRR retrievals of r to one set of microphysical data for the entire ASTEX period although many microphysical measurements were taken. Matching the time and location of the satellite overpasses with the aircraft measurements is generally secondary to the other experiment goals. Additionally, the aircraft can only fly at one level making the comparisons even more limited (e.g., Nakajima and Nakajima, 1995). Ou et al. (1995) were able to eliminate the vertical distribution problem by using microphysical data taken by a balloon-borne instrument that passed through cirrus clouds. That type of validation, although very accurate, is limited to a few satellite pixels, is labor intensive, and provides a minimal statistical base. Despite their limitations, in situ measurements should be continued with the main priority of verifying other high-resolution techniques such as the radar-radiometer methods (e.g., Matrosov et al., 1992) that can provide much more data over longer time periods. Secondarily, the in situ data should be used, in the absence of the other methods, to directly assess the uncertainties in the satellite retrievals of r, D, WP, and τ.

b) CONSISTENCY STUDIES

A relative measure of the uncertainties in a given parameter can be obtained by deriving the quantity from two simultaneous compatible remote sensing datasets. Such simultaneity may be achieved using combinations of satellites such as GOES-8 and AVHRR or GOES-8 and GOES-9 in pre-launch studies. After launch, the VIRS and GOES, VIRS and MODIS, or VIRS and AVHRR can be used together. Combined aircraft and satellite data can also be used for the same purposes if the scale differences are taken into account. Or multiple passes over the same scene at different angles by the same aircraft can serve the same purpose. Both multi-angle and equal angle datasets should be used. The latter provide a baseline estimate of the differences due to the instrument characteristics. These types of studies are extremely useful for testing the various assumptions and models that are used in the various retrieval methods (e.g., Minnis et al., 1993). For example, P, τ, and D or r should be the same regardless of the viewing angle. The rms differences in these quantities can provide an estimate of the relative error and an overall assessment of the reliability of a given part of the COPRS. Bias errors must be determined using the data intercomparisons described earlier. Angular consistency analyses should also be performed over areas with the in situ and active sensors to improve provide a more complete evaluation of the retrieval errors.

Satellite consistency studies can be implemented without field experiments and can provide a large statistical database over a variety of surfaces, climates, and times of day. However, they require considerable investment in data acquisition, algorithm preparation, intercalibration, and spatial and temporal matching. Nevertheless, they are essential to obtain the types of statistics needed to establish firm uncertainty estimates of the COPRS products.

c) SENSITIVITY STUDIES

Cloud scenes are observed at various angles at different times of day. The dual satellite approaches can only yield relative errors and will only sample a few angular conditions. Therefore, it is essential to theoretically examine the effects of variable viewing and illumination conditions on the COPRS parameters over a full range of cloud types and background conditions. Radiative transfer calculations should also be used in simulations to estimate parameter errors due uncertainties in the input radiances and correlative data. Because clouds are not often plane parallel sheets, theoretical studies using advanced radiative transfer models should be performed to evaluate the effects of three-dimensional inhomogeneities in the various cloud properties on the plane-parallel model retrievals. Such studies may lead to the design of techniques to empirically correct the retrieved parameters.

4.3.2.3 Measures of Success

Successful validation of all of the COPRS products is completed when the uncertainties have been determined both theoretically and empirically over all major background and climate types for both multi-layer and single-layer clouds for the full range of applicable viewing angles at all times of day. This effort should be carried out in steps to successfully validate the retrievals for a few of the more important conditions. Thus, the validation efforts should concentrate on a few major climate regimes and backgrounds. For example, convective clouds and cirrus dominate a significant portion of the tropics, low stratiform and scattered cumulus exist over large portions of the marine subtropics, highly variable storm systems prevail over the midlatitudes, and a wide variety of ice and water clouds occur over the cold bright backgrounds of the polar regions. It is suggested that these regimes, which have already received some scrutiny, be the focus of the initial validation efforts.

When stable statistical measures of uncertainty are achieved from theoretical and empirical efforts in each climate regime, it will be possible to claim the validation as a success. Stable statistics refer to rms and bias errors, that, when averaged with previous estimates, do not substantially change the overall uncertainty in a given quantity. Ideally, the uncertainties should be developed for the various factors noted in the beginning of section 4.3.2.2 to maintain statistical independence of the data used to assess the overall error for a given climate regime. This approach is encouraged but may not be realistic for all of the variables.

Another measure of successful validation will be pre- and post-launch consistency in the variable values and in the multi-satellite intercomparisons. Agreement between the theoretical and empirical uncertainty estimates may also constitute a successful validation because it indicates a relatively complete understanding of the physical processes involved in the retrievals.

4.3.3 PRE-LAUNCH ALGORITHM TESTING AND DEVELOPMENT

The pre-launch phase will test the algorithms by applying them to satellite and aircraft radiance datasets taken during field programs or coincidentally with other correlative data. The satellite data include AVHRR, Meteosat, GMS, Landsat, GOES-6&7, and GOES-8&9. Radiances measured by the ER-2 MAS, AVIRIS, and the ARM/UAV MPIR can be used as satellite surrogates. All or part of the COPRS algorithms will be or have been applied to these datasets to determine one or more of the considered parameters during various experiments.

4.3.3.1 Field Programs

Cloud truth values can be derived from aircraft, surface, and other satellite data taken during the several field programs. These experiments are divided into various climate regimes. and listed in Table 4.3-2. Tropical clouds can be examined using data from TOGA/COARE, CEPEX, MCTEX, ARM/TWP, the 1996 cruise of the ship Discoverer, STERAO-B, and SCAR-B. Midlatitude and subtropical continental clouds are the subjects of FIRE-I Cirrus, ICE, FIRE-II, BOREAS, FRIZZLE, RACE, PSUCS, WISP, Arizona 1995, SUCCESS/FIRE, SCAR-C, and ARM/UAV. Subtropical and midlatitude marine clouds are the foci of FIRE-I Stratocumulus, ASTEX, CASP, NARE, EUCREX'94, ACE1, FASTEX, and ACE2. ARMCAS ARM/NSA are devoted to measurements of polar clouds.

Extensive aircraft measurements are part of most of these field campaigns. The cloud truth aircraft data comprise in situ measurements of cloud particle number density, phase, size, and shape; cloud water content; and, through vertical integration, optical depth, water path, and effective particle size. The last three parameters are directly comparable to the satellite- or radar-derived properties if properly averaged. Surface data from these experiments include measurements taken by uplooking radar and radiometer systems, sun photometers, interferometers, narrowband infrared radiometers, shadowband radiometers, microwave radiometers, and depolarization lidars. The radar/radiometer systems can be used to derive vertical profiles of cloud phase, effective particle size, and water path. Integration and averaging of these profiles yields values comparable to the COPRS output. Sun photometer and shadowband radiometer data can be analyzed to determine cloud optical depths during the daytime. The accuracy of these results decreases with increasing optical depth. Interferometers and narrowband radiometers are valuable for estimating the spectral emittance of non-black clouds. Presumably, the surface-derived emittances are comparable to their COPRS counterparts. Cloud liquid water path and the presence of cloud liquid water can be determined from passive microwave radiometer measurements. Cloud phase can be profiled for thinner clouds using depolarization lidar data. Cloud liquid water path can also be determined over ocean areas using SSM/I microwave radiometer data.

4.3.3.2 Operational Networks

Various cloud properties are or will be regularly observed with active and passive surface systems at the University of Utah, Penn State University, ARM/SGP, ARM/NSA, the ARM/TWP sites, and NASA Langley's Walker Tower. The ARM sites and PSU generally have the most complete suites of instrumentation. The site in Salt Lake City, Utah has a complement of lidars, a radar, and narrowband infrared radiometer. At this time, Walker Tower primarily is a radiation measurement facility but includes a multispectral shadowband radiometer for cloud optical depth, a hand-held sun photometer, and a laser ceilometer. Relatively frequent lidar measurements of clouds are also taken at NASA Langley Research Center in Hampton, Virginia.

4.3.3.3 Existing Satellite Data

An enormous, growing archive of satellite data is available for both consistency studies and intercomparisons with field data. In addition to the relatively expensive, commercial and government archives of Landsat, AVHRR, GOES, SSM/I, GMS, and Meteosat, there are new, potentially less expensive sources such as the Pathfinder project and the various NASA DAACs. The ISCCP also maintains an archive of sampled AVHRR and geostationary satellite data. These data plus those from other satellites such as the ERS series, ADEOS-I, and RADARSAT may prove useful for addressing some of the COPRS validation needs.

4.3.4POST-LAUNCH ACTIVITIES

4.3.4.1 Planned field activities and studies

After the launch of TRMM/CERES and EOS-AM1, subsets of the operational COPRS products will be compared to field data similar to those used during the prelaunch study. At this time, field experiments scheduled for 1998 and later include INDOEX and FIRE-III in the Tropics and SHEBA and FIRE Arctic Stratus in the polar regions. The Walker Tower, PSU, Utah, and the three ARM sites will likely continue regular monitoring of clouds during the post-launch period. Special efforts should be made to obtain relevant datasets from other programs of opportunity and to develop some special CERES validation aircraft flights. The theoretical studies discussed earlier are ongoing and will continue during the post-launch phase.

4.3.4.2 New EOS-targeted coordinated field campaigns

Prelaunch activities plus the scheduled post-launch programs will not meet the COPRS needs. For example, there is an insufficient number of nocturnal, mountain, and desert cloud studies. The microphysical properties of clouds deriving from intense deep convection such as that over the Amazon Basin or over the midlatitude continents during Spring have not been examined in situ or with active remote sensors. Background characteristics are critical elements in the retrieval process, especially for optically thin clouds. The backgrounds near coasts and over deserts and mountains are extremely variable. Furthermore, the processes driving cloud formation in these areas may be different than those for simple convection, frontal storms, and marine stratocumulus. Thus, in addition to sponsoring new campaigns for developing validation sets over the larger climate systems, EOS should target some of the more difficult situations such as those that occur over mountains, deserts, and coasts. During all of the field experiments, more effort should be devoted to taking measurements at night and in situ data for multilayered clouds.

4.3.4.3 Needs for other satellite data

Some of the multiple satellite studies conducted before the CERES launches should continue during CERES to verify the previous assessments and to insure that products developed from the MODIS and VIRS imagers behave similarly to those determined using prelaunch datasets. Thus, satellite data from the new GOES imagers, AVHRR, and SSM/I should be made available for COPRS validation.

The other instruments on the EOS satellites will also be needed for the validation effort. For example, the TRMM microwave data can be used like the SSM/I to derive *LWP* over water surfaces. Because it will be coincident with the VIRS data, it will be possible to make direct comparisons. Data from the ENVISAT and ADEOS-II may also be useful for COPRS validation efforts.

4.3.4.4 Measurement needs at validation sites

The long-term validation (e.g., ARM) sites should include microwave radiometers to determine *LWP*; sun photometers and multispectral shadowband radiometers to derive optical depth; radars to determine cloud thickness, cloud microphysical properties, and vertical and horizontal structure; lidars to detect phase variations in clouds, cloud boundaries, and optical depth for thinner clouds (item especially needed at night); infrared beam radiometers to estimate emittance; and radiosonde data to determine vertical humidity and temperature profiles.

In situ measurements should be taken periodically over the long-term sites to insure that the algorithms applied to the validation instruments are performing properly. Similar measurements of cloud particle size, phase, and shape, cloud water path, and optical depths should be performed intensively during the field campaigns.

4.3.4.5 Needs for instrument development

Because the number of long-term validation locations is so small, more sites are needed to represent other climate regimes. To make the installation and maintenance of such sites possible, instrument development and algorithm automation will need to be pursued. For example, smaller, less expensive radars that draw less power would be critical to such efforts. Similar advances in the other instruments would also be welcome. The logistical problems involved in deploying instrument suites in remote areas such as deserts, mountains, or on ocean buoys should also be considered in the development. determination of site locations may require extensive analysis of prelaunch global COPRS datasets. Current sites that do not have a full complement of instruments should be encouraged to obtain them and make them operational. Other institutions that have some of the necessary hardware should be called upon to deploy their instruments and analyze their datasets.

4.3.4.6 Intercomparisons

The COPRS can produce different values for the same cloud properties because of multiple algorithms in the subsystem. Thus, one of the first -order intercomparisons should be between the various COPRS results. Why they differ and when should be understood as well as possible. When both the TRMM and AM-1 are operating together, the COPRS results from both satellites should be compared whenever the satellite cross. MODIS and COPRS datasets should also be examined together for the same purpose. The COPRS datasets should also be compared to LWP derived from the SSM/I and TRMM data as noted earlier. Other comparisons between in situ, ground and aircraft sensors, and other satellites should be performed as discussed earlier.

4.3.5 VALIDATION RESULTS IN DATA PRODUCTION

4.3.5.1 Approach

The COPRS validation effort will require special datasets derived from the CERES data processing stream. These special sets include all of the data for each imager pixel in the specified time and space validation window. The correlative data associated with each pixel and the raw imager pixel radiances are also included in the special datasets. During a validation period, full pixel data will be extracted over the specified geographical region during every CERES overpass. Ongoing, quicklook products, such as graphical representations of the parameter fields, are needed for visual evaluation of the CERES output. This step is a critical first-line validation of the data. It requires experienced scientists for proper execution.

4.3.5.2 Role of EOSDIS

The EOSDIS should facilitate access to the required satellite and validation site datasets. In that capacity, it may serve as a repository or connection for relevant field program data. Current NASA DAACs are already filling this role to a certain degree. The acquisition of non-operational and other EOS satellite data should be undertaken by EOSDIS to minimize redundancy and amplify the utility of the correlative satellite datasets.

4.3.5.3 Plans for Archival of Validation Data

The EOSDIS DAACs should continue to archive the field program data and expand its connection to other archives of relevant data. For example, there should be links between the EOSDIS and ARM archives to smooth the acquisition of the necessary validation sites. Other validation site operators should be encouraged to submit their datasets to the EOSDIS for more widespread use. Combined CERES-outside validation datasets used by the CERES Science Team or validation collaborators should be archived by EOSDIS after the initial studies are completed.

4.3.6 SUMMARY

The CERES COPRS validation plan is an ambitious effort directed at the determination of the uncertainties in the cloud microphysical properties derived from the VIRS and MODIS imagers. It requires both theoretical and empirical studies that will employ large quantities of satellite data, a variety of field programs, long-term monitoring sites, and numerous modeling studies. The remote sensing of cloud properties is a relatively new science examining a very complex system. Necessarily, the validation of the derived products is an involved task. Success in this effort will be determined by convergence of the uncertainty estimates. Thus, expanding the statistical representation of the correlative data is essential. The approach builds from the small-scale in situ data to larger time scales based on continuous measurements at the surface. Intercomparisons of the surface and satellite retrievals provides a measure of the absolute errors in the products. Comparisons of multiple satellite retrievals over large areas at various angles establishes a large statistical database that will provide angle and scene-dependent estimates of relative errors as well as precision of the results. Theoretical calculations lead to error estimates arising from the various physical constraints on the retrieval system. These modeling approaches can be used to better understand the errors and to search for methods to minimize them. Together, the theoretical and empirical analyses should provide a quantitative estimate of each COPRS product for a variety of conditions.

This effort calls for the development of additional programs to measure cloud characteristics with aircraft and surface instruments in climate and surface-type regimes neglected in earlier studies. Expansion of long-term monitoring of cloud properties from surface sites is also requested. The COPRS validation datasets should combine CERES COPRS and correlative data in a scientific archive, preferably, EOSDIS, to provide for more scientific analysis.

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4.3.8 LIST OF ACRONYMS

ACE Atmospheric Chemistry Experiment

ADEOS Advanced Earth Observing System

ARM Atmospheric Radiation Measurement Program

ARMCAS Arctic Radiation Measurements in Column Atmosphere-surface System

ASTEX Atlantic Stratocumulus Transition Experiment

AVHRR Advanced Very High Resolution Radiometer

BOREAS The Boreal Ecosystem-Atmosphere Study

CASP Canadian Atlantic Storms Program

CEPEX Central Equatorial Pacific Experiment

CERES Clouds and the Earth's Radiant Energy System Project

COPRS Cloud Optical Property Retrieval Subsystem

DAAC Distributed Active Archive Center

ENVISAT Environmental Satellite

ERBE Earth Radiation Budget Experiment

ERS Earth Resources Satellite

EUCREX'94European Cloud Radiation Experiment 1994

FASTEXFronts and Atlantic Storm Track Experiment

FIRE First ISCCP Regional Experiment

FRIZZLEFreezing Drizzle Experiment

GOES Geostationary Operational Environmental Satellite

GMS Geostationary Meteorological Satellite

ICE International Cirrus Experiment

INDOEXIndian Ocean Experiment

ISCCP International Satellite Cloud Climatology Project

MAS MODIS Airborne Simulator

MCTEXMarine Continental Thunderstorm Experiment

MODISModerate Resolution Imaging Spectrometer

MPIR Multispectral Pushbroom Radiometer

NARE North Atlantic Regional Experiment

NSA North Slope of Alaska

PSU Pennsylvania State University

PSUCSPSU Continental Stratus Experiment

RACE Radiation, Aerosol, and Climate Experiment

SCAR Smoke Clouds and Radiation Experiment

SHEBASurface Heat Budget in the Arctic

SSM/I Special Sensor Microwave/Imager

STERAOStratosphere Troposphere Experiments: Radiation, Aerosols, and Ozone

SUCCESSSubsonic Cirrus and Contrails Special Study

TOGA/COARETropical Ocean Global Atmosphere/Coupled Ocean Atmosphere Response Experiment

TRMMTropical Rainfall Measurement Mission

UAV Unmanned Aerospace Vehicle

VIRS Visible and Infrared Scanner

WISP Winter Icing Storms Project

CERES 1
VALIDATION OF IMAGER CLOUD OPTICAL PROPERTIES

DATA PRODUCTS

CLOUD *PHASE, EFFECTIVE PARTICLE SIZE, WATER PATH, OPTICAL DEPTH, EMITTANCE, RADIATING TEMPERATURE, & THICKNESS*

MISSIONS

TRMM, EOS AM-1, & EOS PM-1

APPROACH: BOTH PRE- & POST-LAUNCH

• COMPARISONS WITH *IN SITU & SURFACE/AIRCRAFT REMOTE SENSING*

YIELDS ESTIMATE OF BIAS ERRORS

• SIMULTANEOUS RETRIEVALS FROM *MULTIPLE SATELLITES OR AIRCRAFT & SATELLITE*

PRODUCES STATISTICS, RELATIVE ERRORS, & SCENE/ANGLE DEPENDENCE

• MODEL CALCULATIONS TO *DETERMINE ALGORITHM SENSITIVITIES TO INPUT & ASSUMPTIONS*

LEADS TO PHYSICAL UNDERSTANDING OF OBSERVATIONS

CERES 2 VALIDATION OF IMAGER CLOUD OPTICAL PROPERTIES

PRELAUNCH

- **COMPLETE ANALYSES OF FIELD PROGRAM DATA & COMPARE WITH SATELLITE RETRIEVALS**
- **DEVELOP & ANALYZE MATCHED SATELLITE DATASETS HAVING APPROPRIATE SPECTRAL CHANNELS**
- **STUDY ALGORITHM SENSITIVITY TO CLOUD INHOMOGENEITIES, VIEWING & ILLUMINATION CONDITIONS, BACKGROUND, & INPUT**
- **IDENTIFY KEY CLIMATE REGIMES NEEDING FURTHER VALIDATION**

POST-LAUNCH

- **INCREASE NUMBER OF LONG-TERM MONITORING SITES**
- **DEVELOP FIELD PROGRAMS & INSTRUMENTS FOR LONG-TERM DEPLOYMENT**

- **PERFORM QUICK-LOOK ANALYSES OF GLOBAL PRODUCTS**

- **COMBINE FULL-RESOLUTION CERES AND VALIDATION SITE DATASETS, PERFORM COMPARISONS**

- **COMPARE RETRIEVALS TO THOSE FROM OTHER SATELLITES & INSTRUMENTS**

EOSDIS

- **FACILITATE DATASET ACQUISITION**

- **ARCHIVE COMBINED CERES & CORRELATIVE DATASETS**